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Workshop on Fire Protection Technology

A Record of the U.S. Papers Prepared for the Workshop on
Fire Protection Technology

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U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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WORKSHOP ON FIRE PROTECTION TECHNOLOGY

(A Record of the U.S. Papers Prepared for the Workshop on Fire Protection Technology held in Cairo, Egypt, April 27-28, 1986)

U.S. Papers:

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April 1986

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
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FOREWORD

Within the framework of the Applied Science and Technology Research Program between the Governments of Egypt and of the United States of America, the National Bureau of Standards (NBS) is executing a program of assistance to Egyptian Standards Organizations. The NBS program is financed under a Participating Agency Service Agreement (PASA) between the United States Agency for International Development (AID) and the National Bureau of Standards. The Egyptian organizations involved are the Egyptian National Institute for Standards (NIS), under the Egyptian Academy of Scientific Research and Technology, and the Egyptian Organization for Standardization and Quality Control (EOS), which is a dependency of the Ministry of Industry of the Egyptian Government. Through NIS, NBS also interacts with the Assay and Weights Administration, which is under the Weights and Measures Service of the Ministry of Supply and Trade.

The aim of this program is to strengthen systems of measurement, calibration, standards and quality control in Egypt and to promote the research in metrology on which these activies are based. But to translate the progress being achieved in the Egyptian institutions into changes beneficial to the economy and productiveness of Egypt, we must ensure that the services of these institutions are fully known, recognized and utilized by the industries.

To promote such interaction NBS assisted the National Institute for Standards, in organizing a workshop entitled "Fire Protection Technology" which was held at the Meridien Hotel, Cairo, April 27-28, 1986. The contributions prepared by the U.S. speakers are reproduced here. We hope that this workshop and publication achieved their aim to make our viewpoints on the value of fire safety known to the intended audience.

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The National Bureau of Standards and Its International Programs

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Industrial development and growth, and the advancement of the quality of life, are impossible in this industrial era without an adequate measurement capability and without an organization which puts this capability at the service of the nation. Without measurement skills, it is impossible to control the quality of industrial production, the economy of production processes, and the fabrication of the innumerable devices and products that interact with other devices and products. As international commerce becomes more vital for the internal economy of each country, the establishment of international standards linking the measurement networks of all nations becomes equally important.

An industrializing nation must also pay attention to the hazards of daily life, and establish norms and regulations which minimize the effects of fires, earthquakes, collapses of buildings, toxic effects of impurities in air, water, foodstuff and medications. All these safeguards are impossible to establish without adequate measurement capabilities.

The necessity for standardizing the devices used to provide safety to the public was brought to light painfully in an episode which is germane to this workshop. In 1904 a fire broke out in the city of Baltimore. It propagated quickly through the buildings and streets, until a large part of the city was involved; the disaster went on for several days. Firefighters arrived at the scene from cities as far as Washington and New York. When they prepared to connect their hoses to the fire hydrants, they discovered that this could not be done because the dimensions of the connectors varied from city to city. As a consequence, the firemen from out of town could not provide effective help to the local forces, and much of Baltimore was destroyed in the disaster.

To assist their industries with measurement problems, and to safeguard against the occurrence of incidences such as I have just described, all countries create institutions which provide a national focus of metrology, and coordinate their measurement units with those of other countries. In Egypt, the primary responsibility for this task is given to the National Institute for Standards (NIS), which is the Egyptian sponsor of this workshop; in the United States of America, the corresponding institution is the National Bureau of Standards (NBS).

NBS was created in 1901, only three years before the Baltimore conflagration, by the Congress of the United States. At that time, the American industry was developing rapidly, and the need for this measurement center was keenly perceived by industry and science. The structure and functions of NBS arise from historical necessities, and there are not two corresponding institutions in the world which have exactly the same characteristics. For instance, NBS, unlike similar institutions in many other countries, is not involved in law-enforcing processes, and only to a very small extent in the writing of engineering standards. Its dominant concern is measurement, and to understand measurement in all spheres of technology requires the study of the physical and chemical sciences which describe the measurement processes as well as the characteristics of the things to be measured. In this process, NBS quickly became an important resource to other government agencies which needed its services in diverse technological problems. The present structure of NBS can be seen in Table 1.

Besides the scientific studies mentioned above, NBS provides services of measurement and calibration, distributes standard reference data referring to various physical sciences, and distributes at cost standard reference materials which can be used for secondary calibration in science, medicine, industry and commerce.

NBS is the custodian for the United States of the primary standards for quantities such as length, mass, time and frequency, electrical and thermometrical units. The coordination of these standards with the international standards, through the International Bureau of Weights and Measures, is one of the international activities of the institution. NBS also represents the United States of America in other international bodies such as the International Organization of Legal Metrology, and in the discussions of the Economic Commission for Europe.

The provision of calibration services and standard reference data, and the distribution of standard reference materials is another facet of international cooperation. NBS also hosts scientists from all over the world to work as guests in our laboratories, and at present we have approximately 165 foreign scientists working with ours for periods which vary typically from 6 to 24 months.

We also cooperate in special programs with many nations, either under direct agreements between a foreign institute with NBS or within the framework of agreements between nations. Such cooperation tends to strengthen the technical capabilities of both participating institutions, as well as give us a mutual opportunity to know better our colleagues in other countries. The present workshop on fire protection technology is part of the cooperation of NIS and NBS within the framework of the Applied Science and Technology Research Project, executed by the Egyptian Academy of Scientific Research and Technology, and the U.S. Agency for International Development. I hope that it will contribute to strengthen the friendship between our two nations, and to help you to improve fire prevention measures in the Arab Republic of Egypt.

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

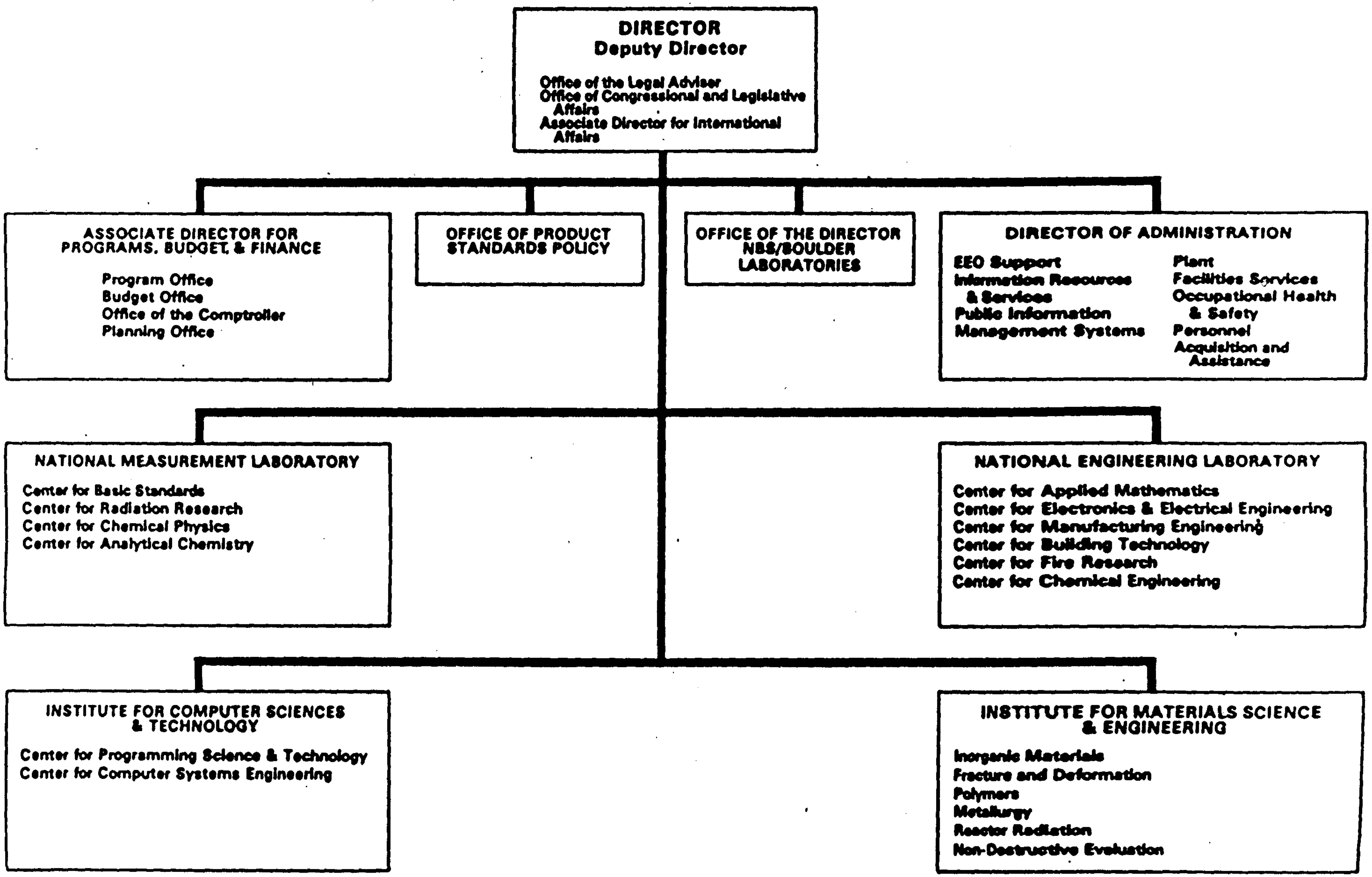

TABLE 1

JULY 22, 1985

FIRE TESTS IN THE UNITED STATES

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1. Introduction

This paper will talk about the use of fire tests in the United States; and their relationship to the codes and standards. Generally, most tests have been developed to answer a regulatory need and are either directly referenced in the codes or used as part of the product acceptance criteria in the code system. The tests can be categorized as follows:

- flame spread
- fire resistance
- non-combustibility and heat release
- furnishings
- electrical
- mechanical

2. Flame Spread

The ASTM E84 test is one of the most widely used fire test. This test evaluates the rate of flame spread that will occur in a fire under a forced draft. It attempts to simulate the drafts that would occur along the surface of a wall or ceiling lining by using an air draft of 73 m/min.

through the test chamber. The test is conducted in a chamber that is 7600 mm long and 450 x 305 mm cross section. A burner at one end is supplied with gas at a rate of 5.3 MJ/min. The rate of travel of the flame spread along the specimen, which is on the top of the chamber, is then measured. The time-distance relationship is converted into a set of flame-spread classifications. These classifications are used to regulate wall and ceiling lining materials both within rooms and in corridors, stairways and exits. Although the test has also been used to measure smoke development, its use in the regulations is for flame spread classification.

The E648 test is used to evaluate floor covering systems. This test uses a radiant panel which is inclined at a 30° angle with a horizontal specimen. The specimen forms the bottom of the test assembly, and is mounted similar to the way it would be on the floor in a room. For instance, if the specimen is a carpet, and is to be installed over a resilient pad, it would be so mounted for the test. The radiator imposes a varying flux from 11 to 1 kW/sq. m. along the length of the test specimen. The distance which the fire travels along the specimen is used to measure the susceptibility of the flooring material to the spread of flame. This distance is translated into a critical radiant flux - the minimum flux from the panel needed to sustain flame spread. The regulatory codes have used this critical flux for regulating carpeting in both rooms and corridors. A similar test is E970 which is used to evaluate attic insulation in buildings. This test uses the same equipment as the E648 test and measures the critical radiant flux for insulation used in ceilings. Its use is mandated in federal regulations by CPSC (Consumer Product Safety Commission) for governing the flammability of insulation in residences.

Another flame spread test is the UL901 test for cables. This test is an adaptation of the E84 test. The test cables are in a tray suspended from the ceiling of the furnace. This test has been used to evaluate whether electrical cables can be classified as low flame spread and **are therefore allowable for use in air plenums.**

3. Fire Resistance Testing

The ASTM E119 test is the oldest ASTM fire test. It originally dates back to about the early 1900's; and it is used to evaluate beams, columns, wall, floor and ceiling constructions. Comparable fire tests, E152 and E163, are used for doors, and windows. More recently test E814 has been adopted for the evaluation of penetrations in walls and floors. These tests all follow the same time exposure curve which is comparable, but not identical, to the ISO fire resistance curve. The test appears in all the building codes and the fire resistance is generally specified as 1, 2 or 3 hour fire resistive requirements. The fire resistance specified depends upon the size of building, height, and its occupancy. The E119 test has detailed information about moisture levels at testing and moisture corrections, since this factor has been found to be important in fire test results. Also information on estimating the degree of restraint to be applied to beam ratings is needed, since beam fire resistance ratings will vary with the design restraint. There are multiple publications in the U.S. that list the many types of constructions that have been tested for fire resistance; and these test results are incorporated in the building codes.

The fire resistance of roofing is controlled by the E108 test method, which includes a series of tests: intermittent flame exposure, spread of flame, burning brand, flying brand, and rain test. Various sizes of burning wood brands are placed on the test roof, depending upon the classification desired. The test specimen is 1000 mm wide by 1300 mm long for all tests except the flame test, which requires a 1000 x 4000 mm sample. This test is used to control roofing fire resistance, depending on the type of building and the occupancy.

4. Non-Combustibility and Heat Release

Most of the codes require non-combustible components in the construction of the more fire resistive buildings. The non-combustibility test that is referenced in the codes is ASTM E136. This test uses a refractory tube, 76 mm diameter and 210 mm long, which is heated to 750°C. A sample is plunged inside the ceramic cone and measurements are taken of the temperature rise and weight loss; and observations are made on the presence of flaming. The NFPA test #259 for potential heat of building materials is referenced in some of the NFPA (National Fire Protection Association) fire standards. This test measures the amount of heat that would be contributed when a material is exposed to a 750°C fire. This test is used to define materials of "limited combustibility".

The ASTM E906 test measures the rate of heat release of materials. In this test, materials are subject to a radiant flux at different specified levels from 10 to 50 kW/sq.m. and the rate of heat release is measured. This test is not currently used in building codes. However, it has been specified for use by the FAA (Federal Aviation Administration) for materials in airplane interiors.

5. Furniture and Furnishings

Curtains and draperies are regulated by NFPA 701. This test consists of two parts: a small scale and a large scale test. Normally both of these tests are employed on any decorations in a building, including curtains and drapes. In the small scale test a 70 x 250 mm specimen is mounted vertically and subject to a small burner. The length of char is measured and its maximum value is specified. In the large test four samples of 127 x 2130 mm are hung vertically to form 4 folds. The specimens are also subject to a small burner and the length of char is determined.

NFPA 260A and 260B specifies tests to measure the ignition resistance of furniture. There are 2 tests, one to evaluate the components of the furniture and the other to evaluate an assembly of the components. In general the component test is used to regulate furniture inside rooms, whereas the assembly test is used for furniture in public spaces.

6. Mechanical Tests

There are multiple tests that are used to approve equipment for heating, ventilating, and air conditioning systems. For example, UL181 is a product standard for ducts used for moving air. This standard combines several different fire test methods. From these tests ducts are classified. The building codes refer to this standard for duct classification. Similarly there are product standards for various types of furnaces, heating units and chimneys. Listing or approval under these standards is required by building code officials; and they are referenced in the regulatory codes as "listed appliances".

7. Electrical Tests

The building codes require materials or electrical installations which conform to NEC (National Electrical Code, NFPA 70). This code relies heavily on the UL* listings of materials. These listings in turn include multiple fire tests. A common example is UL94 which is the standard test for flammability of plastic materials that are used in appliances. This test uses a sample 13 mm wide by 127 mm long. The specimen can be oriented either horizontal or vertical and is tested by exposing it to a small burner at one end. There are multiple classifications that are derived from the test. All electrical appliances and material components are evaluated for either overheating or fire potential by various types of tests that are generic to the particular electrical equipment.

* Underwriters Laboratory

8. Summary

In general, we have reviewed some of the fire tests which are commonly used in the regulatory field in the United States and given a very brief idea of the nature of each test.

FIRE SAFETY CODES IN THE UNITED STATES

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I. Introduction

There are different types of safety codes in the United States. They primarily come under the categories of construction, installation, or maintenance codes. Construction codes are applicable when the building is constructed and govern the design of the building and the use of materials in the building. Building codes may be divided into architectural, mechanical, and plumbing requirements.

The installation codes govern the procedures for the safe installation of certain key equipment. For example, the National Electrical Code covers the installation of electrical wiring. We also have a sprinkler code, a standpipe code, and a detector code. There are in addition multiple other codes for the installation of specialized equipment such as industrial ovens, kitchen equipment, and so forth. The National Fire Protection Association publishes over two hundred codes in this category.

Finally, there are the maintenance codes which are normally called "fire codes". These codes deal with the operation of the building and limit the uses of the building, storage of hazardous materials, and maintenance of the systems that are required for life safety within the building.

All the codes within the United States derive their legal authority from the fifty states. There are no federal codes, nor does the federal government have jurisdiction. The states may promulgate their own codes, use nationally recognized standard codes, or delegate their authority to the cities and towns to develop and enforce their own codes. In general, regardless of who promulgates or enforces the codes, the legal authority is based on the right of the state to provide regulations for the safety and welfare of its inhabitants. The typical building code in the United States has about three quarters of its contents dealing with fire safety and the other one quarter dealing with structural design.

The concept of the building codes has been based on the ability of the people to evacuate a building safely. The early codes in the beginning of the Twentieth Century were designed primarily to prevent conflagrations between buildings. The code features were then revised to prevent burnout within a building; and currently, the codes are designed to provide for safety on a single floor of a building. Essentially, the codes are designed to prevent multiple deaths, but not necessarily to prevent an individual death from occurring.

II. Building Codes

The codes generally start out with a description of the type of occupancy. All buildings are divided according to the type of the people and the usage of the building: generally, into about ten divisions with some subdivisions. The requirements for the buildings vary according to the occupancy use since this reflects different degrees of hazard, and therefore the need for different levels of fire safety. In addition, buildings are divided by the type of construction. In general, they are catagorized into combustible or noncombustible types, as a function of the amount of fire protection that they have received. The occupancy and type of construction determine the height and area of the building that is allowed. That is, the number of stories in the building and the number of square meters per floor are determined from the hazard associated with the occupancy and the type of construction of the building. The codes also have provisions for special types of buildings such as high-rise buildings, parking structures, covered malls and atriums.

A large part of most building codes deal with the egress system. Considerable attention is paid to the adequate size of evacuation routes, the number of routes, the size of the doors, the control of smoke movement within the building, and the construction of the escape routes.

There are requirements for materials that are used in the buildings. These are particularly applicable to the linings or interior finishes of the walls, ceilings, and floors of the building. The requirements are more restrictive in the escape routes than they are in the rest of the building, but all are covered.

Other requirements cover such things as mechanical equipment systems, furnaces, ovens, chimneys, and stacks; and there are requirements for the fire resistance of various types of doors, floors, walls, windows, and the treatment of openings within these fire resistive barriers.

The plumbing code section of the code is designed to govern the requirements for potable water supply and sanitation in buildings. It is the most prescriptive section of the code, and it covers such things as the materials to be used in the water supply system, the amount of water that should be supplied per individual person, and methods of installation.

III. Installation Codes

These cover a tremendous amount of different types of equipment from very specialized types, such as industrial ovens, to basic building requirements, such as sprinkler and standpipe systems. A typical example is the National Electrical Code. This code is designed to provide for the safe installation of electrical systems in a building, protecting against electrical shock or possibility of fire. The code covers the design of the wiring system, the allowable materials that can be used and their limitations, specifications of various types of equipment such as lighting fixtures, electrical heaters, electric motors, air-conditioning equipment, and how they should be installed.

IV. Maintenance Codes

Whereas the previously mentioned codes were all enforced by the building inspectors during the time of construction, maintenance codes relate to the operation of the building and are enforced periodically by the Fire Brigade. One such code is called the Fire Code. This code has provisions for the maintenance of fire protection and life safety systems in a building, such as the sprinklers, detectors, and standpipe systems, and for maintaining the integrity of the fire resistive walls and partitions. There are fire safety provisions governing incinerators, the storage and use of flammable material, and uses of the building itself. The code also covers the maintenance of the exitways to make sure that the interior finishes are not degraded and the exitways are not obstructed.

It has a section which covers maintenance of safe conditions during the the alteration or modification of a building.

V. Model Codes

There are four model codes in the United States: the Uniform Building Code, the Southern Building Code, the National Building Code, and the Life Safety Code. The first three are complete codes: they cover all features of the codes - structural, fire, mechanical, and plumbing. The Life Safety Code is strictly devoted to fire safety for individuals. The codes are adopted by the various states and localities so that most of the codes in the country that are enforced are one of the model codes.

Engineering Applications for Fire Related Prediction Tools

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1. Introduction

Traditionally, the practice of fire protection engineering has involved the application of expert judgement and experience to current problems. This is largely accomplished through the development and use of prescriptive codes, standards, and manuals of practice through a consensus process, by committees made up of such experts. While this system has served us reasonably well in the past, it is not without its weaknesses.

These committees, and the codes which they develop, tend to deal well with traditional problems since they are founded in traditional experience, both with actual fires and with fire tests. More recently, however, technology and materials science have been changing rapidly such that more and more decisions must be made by these committees and by enforcing authorities in the absence of any experience or historical precedent upon which to make such decisions. This situation generally leads to extreme conservatism and redundance leading to increased cost, at least until experience is gained with the new technique or material.

A potential solution to this problem rests in the development of predictive methods which will allow performance based codes by providing a practical mechanism for evaluating the impact of new technology or materials without the necessity for conducting extensive, and prohibitively costly full-scale experimental analyses.

The purpose of this paper is to provide an overview of some of the predictive methods which are currently available to practicing engineers.

2. Predictive Methods

The current fire-related prediction tools have been developed as a direct result of fire research conducted around the world and the availability of low cost, high performance computers. In general, the ability to predict a given fire phenomenon begins with well-designed experiments. Analysis of the data from these experiments produces an empirical understanding of the interrelationship of important variables.

Through the application of the principles of physics, chemistry, fluid mechanics, etc., the process of interest can be described completely in terms of basic properties and physical constants. This represents a phenomenological understanding of the process and a mathematically self-consistent description of it.

The form of the currently-available predictive tools covers a range from simple, algebraic equations through highly complex computer models involving ordinary or partial differential equations. At the simplest end, algebraic equations (generally semi-empirical) have been derived for many processes and are suitable for estimation purposes since they generally deal with steady-state phenomena. Since fire is a highly dynamic process, these steady-state solutions represent inexact but useful techniques for engineering purposes.

Since the presence or absence of safety to a structure or its occupants is highly time-dependent, times to events are of fundamental importance. But the time dependent form of the equations governing a fire related process is generally too complex for hand-calculated solutions. Therefore, fire models have been developed which use the computer to solve these time dependent equations.

Most such computer fire models solve sets of ordinary differential equations as a quasi-steady-state approximation. That is, the transient solution results from a series of short time intervals over which the process is considered to be steady-state. If the selected time intervals are short enough, (of the order of fractions of a second) the assumption of a steady-state process over this short time interval is a good one.

In order to provide a full transient type analysis, one needs to solve a set of partial differential equations for the process of interest. While this is done in some models, it is usually not practical for engineering purposes since the time required for solution, and the computer necessary to solve all of the partial differential equations for even a simple case is impractical for most engineering-related problems. These models do serve a very useful purpose within the research community, however, in that they provide insight into the most basic levels of the physics and chemistry of the process.

3. Algebraic Equations

As stated earlier, a number of algebraic equations suitable for hand calculation have been developed for some specific fire-related processes. Many of these equations have been compiled in a report by Lawson and Quintiere [1], along with a detailed discussion of their use and limits of applicability. Due to the self-explanatory nature of this report, it will not be discussed in detail here. It should be pointed out, however, that Nelson [2] has put most of these equations into a computer program which can be operated on a small desk top computer. This program is not a fire model since it solves each equation independently. Rather, it represents a simplification of use of the included equations.

4. Models for Desk Top Computers

4.1 Fire Models

The fire models described below are of the ordinary differential equation type and were originally developed on larger computers. Advancements in desk-top computer technology and software allowed their transferal to this computing environment. While each of these models is available in a form which operates on IBM PC or other MS-DOS machines, it should be noted that the more complex models will require significant execution times on such small machines for complicated cases.

The simplest of the engineering models is one developed by Cooper called ASET for Available Safe Egress Time [3]. This is a simple single compartment filling model which follows the development of two stratified layers within a single compartment containing a fire. It predicts the upper layer temperature, smoke density, species concentrations, and position of the interface between the layers over time. While basically a single compartment code, it has been used for two-compartment configurations where the code is run first for the fire compartment and then the fire compartment predicted values are used at the source terms for the second compartment calculation. An additional feature provided within ASET is the estimation of time to certain, specified events. These times to events are calculated using the quasi-steady-state approximation.

Another single compartment fire model which is considerably more complex was developed by Smith and Satija at Ohio State University [4]. The OSU Model was developed in order to extrapolate material properties measured in the OSU Heat Release Rate Calorimeter [5] (ASTM E-906) to full-scale room configurations. Thus, the input data required for this model are those data provided by the OSU Test Method. This model is considerably more complex than the ASET Code and provides more in the way of predicted quantities. At present, this OSU Code is the only available fire model that attempts to predict the burning of wall lining materials.

The Harvard V Computer Code [6] represents another increase in complexity over the OSU Code. It was developed by Emmons and Mitler at Harvard University under a grant from the Center for Fire Research. This model is not tied to any particular test method but rather attempts to calculate fire development in a single compartment, including the combustion of multiple fuel items, from basic principles and property measurements. Where necessary, it does contain some empirical constants (for example, a flame spread parameter) and represents the current state-of-art in modeling of the combustion process. As probably the most mathematically complex code currently available on a personal computer, the model will require the longest execution times of any of these currently available models.

The final fire model to be discussed is the only multiple compartment model currently operating on a personal computer. The model, written by Jones, is called FAST for fire and smoke transport [7]. While it does not contain the combustion calculations available in Harvard V, the FAST Model is primarily a fluid dynamics transport model which predicts the transport of energy and mass produced by a burning item throughout multiple interconnected compartments. The model then predicts the environment in each of these compartments over time in terms of the temperatures, smoke densities, and various species concentrations for up to twelve fire products. The FAST Code is particularly capable in terms of its mathematical solving routine and appears to be most capable of solving problems of interest in a reasonable time and without encountering mathematical problems which cause the program execution to stop (convergence problems).

4.2 Engineering Design and Evaluation Models

In addition to fire models, models have been developed for use in engineering design and evaluation of fire protection systems and building features. The first such model is called ASCOS for Automatic Smoke Control Systems Model [8]. This model, developed by Klote, is used for evaluating the design and operation of smoke control systems in large buildings. It includes such tall building phenomena as wind and stack effect and the flow in shafts such as elevator shafts and stairwells.

Another model which is useful for the prediction of the activation time or required spacing for smoke detectors, heat detectors, and automatic sprinklers is a model called DETACT-QS developed by Evans and Stroup [9]. This model takes an input heat release rate history for the burning object and calculates the development of the fire plume and the resulting ceiling jet in terms of its temperature and velocity as it impacts the heat transfer to a thermally activated device such as a heat detector or automatic sprinkler. In addition, based on the results of experiments conducted by Heskestad at Factory Mutual, it can also be used to estimate the activation time of smoke detectors. It should be pointed out, however, that while usable for predicting the activation time of automatic sprinkler heads, it does not attempt to predict the delivery of the extinguishing agent to the fire nor the extinguishing process. Nonetheless, the prediction of activation time and the ability to account for the effect of varying ceiling heights in the response of thermally activated detectors and smoke detectors is useful, not only for the design and installation of the systems, but also as an ancillary feature to the fire models described above.

Finally, there are two major evacuation modeling programs available for personal computers. The first is EVACNET+ developed by Francis and Kisko at University of Florida [10]. This is an evacuation optimization program which predicts the shortest time necessary to evacuate a given structure. It is quite user friendly and can be run on most small computers in reasonable time.

The other evacuation model which is available for personal computers is the Escape And Rescue Model developed by Alvord at the Center for Fire Research [11]. This is not an evacuation optimization model as is EVACNET+, but rather predicts specific evacuation times for given building geometries and occupant capabilities. In addition to unaided evacuation, it contains features which allow the prediction of evacuation times for handicapped or other occupants incapable of self-evacuation in that it includes the modeling of the rescue process by assigned staff or fire department personnel. This is a considerably more detailed program which would require significantly longer execution times than the EVACNET+ model.

5. Data Sources

The biggest problem facing a potential user of any of the methods described above (from hand calculations through computer models) is obtaining the data required by the calculational technique as input. This is because most of these data involve properties which are either not measured or not reported in traditional property test methods.

Traditional test methods have been designed to produce pass-fail answers. Such yes/no results are the easiest for code authorities to enforce under the more traditional expert judgement codes, but they provide no detail on the quantitative performance of the material or product. Therefore, a new generation of test methods is under development which provide the needed property measurements.

Initially, these new generation test methods can serve a similar purpose under traditional code structure by providing quantitative rankings of material performance requiring that some ranking categories be developed. These ranking categories can be developed straightforwardly by testing traditionally acceptable products and using these as points of reference in the overall ranking process. This approach is similar to that which was used to develop the flame spread categories (A, B, C, and D) as applied to the Steiner Tunnel Test (ASTM E-84). Thus, the new test method can be used to replace the traditional test methods in the current code structure and at the same time begin to produce the property measurement data bank necessary for the predictive methods which will eventually lead to performance based codes. An initial report containing such data for use in models and calculations has been published recently by Gross [12].

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FIRE DETECTION AND ALARM SYSTEMS

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Fire Detection

1. Fire Signatures

Fire detectors sense the presence of fire by responding to changes in their local environment which are indicative of a fire within their associated area of coverage. The goal is to select conditions for sensing which appear as early as possible and which are present at levels sufficiently above those which might be produced by non-fire conditions to minimize false alarms. Such conditions are referred to as fire signatures. Not all unwanted fire conditions produce all fire signatures, so optimum detector system design requires that the detector types selected must be matched to the hazard present.

1.1 Heat

Combustion is essentially an exothermic, gas phase chemical reaction. Gaseous fuels combust by breaking bonds in the fuel molecules forming other chemical species and releasing thermal energy. For solid or liquid fuels, some of the thermal energy is needed to produce the phase change to a gas before the actual combustion takes place. This required energy is the heat of gasification. The net remaining energy then goes to increase the temperature of the gases and air leaving the combustion zone. This hot gas rises due to buoyancy to the ceiling and spreads radially outward in a ceiling jet. The temperature and velocity of this ceiling jet govern the heat transfer rate to thermally activated detectors located on the ceiling.

1.2 Smoke

In terms of fire detection, smoke refers to solid or liquid particles released during combustion. The solids are clusters of carbonaceous spherules formed within the fuel rich portions of the flame in a process similar to polymerization. Vapors can condense on a solid core, yielding a liquid covered smoke particle. This condensation process requires that the temperature be below the vaporization temperature while the vapor concentration is still high. In smoldering combustion, essentially all the smoke is in the form of condensed vapors. This is why the smoke from smoldering appears light colored (the liquid is largely water) and the smoke from flaming is dark (mostly carbon). This also means that the particle size from smoldering is larger than from flaming.

1.3 Light

Flames radiate light energy over a broad spectrum. Radiation in the visible and infrared comes largely from thermal energy radiating from the carbon particles within the flame. This is why a hydrogen flame which contains no carbon is invisible. Ultraviolet radiation comes largely from OH radicals and the thermally broadened OH radiation explains why alcohol flames and premixed gas flames appear blue.

1.4 Transport/Losses

Once produced by the fire, the fire signature must travel to the detector to produce a response. Depending on the signature, this transport process takes time, and losses can occur which further delay response. An understanding of this process can help to select optimum detector placement and type for the fastest response to the hazard.

The rising plume above a fire entrains cool air which reduces the temperature and dilutes the particulate concentration. Once it contacts the ceiling, heat transfer reduces the temperature further but particulate losses to the ceiling are generally small. When the ceiling jet reaches the detector the thermal inertia of a heat detector results in a delay in response, but a smoke detector will respond immediately if the particulate concentration is high enough. This is the primary reason why smoke detectors respond faster than heat detectors for most fires.

With flame detectors, the light energy travels in a straight line almost instantaneously. Since the fire is radiating in all directions, the intensity falls off as the square of the distance from the fire to the detector and may be attenuated by any smoke particles through which it must pass. The key thing to remember about flame detection is that the detector must be able to "see" the flame directly, although infrared energy will reflect from surfaces at a reduced level.

2. Types of Detectors

2.1 Heat Detection

Heat detectors are the oldest, simplest, and least costly of the fire detectors in use today. The oldest physical principles used involve the melting or expansion of an element exposed to the environment. Newer types employ the thermoelectric principle (thermocouples), changes in electrical conductivity (thermistors), or the release of a gas adsorbed in a porous salt.

Heat detectors are designed to activate either at a fixed temperature or to a specified rate of temperature rise or both. Rate of rise type detectors normally include a fixed temperature element so that a slowly developing fire will not produce excessive temperatures before detection. Because of their generally slower activation, heat detectors are normally used for property protection.

2.2 Smoke Detection

Smoke detectors are more costly and complex but are considerably faster in detecting fires. They fall in two major categories, ionization and photoelectric (optical) types.

2.2.1 Ionization Type

Ionization type detectors use a small radioactive source to produce ions (charged air molecules) between two electrodes across which an electric voltage is maintained. This voltage causes the ions to move to the electrodes and discharge. This charge transfer is an electric current. When smoke enters the chamber the ions attach themselves to the smoke particles and do not contribute to the current flow. This reduction in current is proportional to the number of smoke particles present. When the current drops to a specified level, an alarm is produced. This signal proportionality to the number of smoke particles makes the ionization type detector particularly sensitive to flaming fires which produce very large numbers of small particles.

2.2.2 Photoelectric Scattering Type

Photoelectric type detectors sense particle concentration optically by the fact that light is absorbed, reflected, or refracted by smoke. Two subtypes of photoelectric detectors are scattering and extinction. The scattering type uses a light source and receiver so arranged that light from the source does not normally strike the receiver. With smoke present, light is reflected or refracted at an angle which causes it to strike the receiver. Scattering type detectors have the advantage of small physical size and are the most common. A disadvantage is that they are generally less sensitive to absorbing (dark) smokes since they absorb a portion of the incident light, reducing the amount of light which reaches the receiver.

2.2.3 Photoelectric Extinction Type

Extinction type detectors use a source and receiver in a direct line. Smoke attenuates the received light by absorption, reflection and refraction, so they are not affected by particle color. The disadvantage is that they require a significant separation between the source and receiver (attenuation path) for proper signal sensitivity. Thus the source and receiver are normally separate units and the beam path is projected across the protected space.

Due to the physics involved, an optical detector's signal is proportional to the mass concentration of particles present. This favors larger particle diameters (and lighter colors) associated with smoldering fires.

2.3 Flame Detectors

Flame detectors sense the infrared (IR) or ultraviolet (UV) radiation emitted by flames. They are generally the most costly, fastest, and most false alarm prone of the fire detectors in use today. Thus their use is normally restricted to "high hazard" situations.

2.3.1 Infrared Type

Infrared radiation is emitted by almost any hot object. Thus, IR detectors need a second signal to differentiate flames. They normally use the principle that flames "flicker" at a characteristic range of frequency (5 to 30 Hz). Other discrimination principles used include looking at two or more wavelengths, including the combination of IR and UV.

2.3.2 Ultraviolet Type

With two notable exceptions, ultraviolet detectors do not need additional discrimination since the wavelengths used only appear in flames. First, the sun emits a narrow UV line within the flame range. This can be filtered out to make the detector "solar blind". The second exception is that an electrical arc is a very strong, broad band UV emitter. Thus UV detectors are very sensitive to arcs.

3. Selection of Detectors

When laying out a fire detection system the design engineer must keep in mind the operating characteristics of the individual detector type as they relate to the area protected. Such factors as type and quantity of fuel, possible ignition sources, ranges of ambient conditions, and value of the protected property are critical in the proper design of the system. Intelligent application of detection devices using such factors will result in the maximization of system performance.

Heat detectors have the lowest cost and false alarm rate but are the slowest in response. Since heat tends to dissipate fairly rapidly (for small fires), heat detectors are best applied to the protection of confined spaces, or directly over hazards where flaming fires could be expected.

Heat detectors are generally installed on a grid pattern at their recommended spacing schedule, at reduced spacing for faster response, or where beams or joists may slow the spread of the hot gas layer.

The operating temperature of a heat detector is usually selected at least 25°F above the maximum expected ambient temperature in the area protected. Pneumatic heat detection systems have a device known as a "blower heater compensator" which is used to prevent false alarms due to the sharp initial heat rise from ceiling-mounted unit heaters.

Smoke detectors are higher in cost than heat detectors but are faster responding to fires. Due to their greater sensitivity, false alarms can be more frequent, especially if they are not properly located.

Smoke detectors do not have a specific space rating except for a 9 meter (30-foot) maximum guide derived from the UL full-scale approval tests which they must pass. Grid type installation layouts are usually not used since smoke travel is greatly affected by air currents in the protected area. Thus, smoke detectors are usually placed by engineering judgment based on prevailing conditions.

Since smoke does not dissipate as rapidly as heat, smoke detectors are better suited to the protection of large, open spaces than heat detectors.

Smoke detectors are more subject to damage by corrosion, dust, and environmental extremes than the simpler heat detectors because smoke detectors contain electronic circuitry. They also consume power, so the number of smoke detectors which can be connected to a control unit may be limited by the power supply capability.

Photoelectric smoke detectors are particularly suitable where smoldering fires or fires involving low temperature pyrolysis of PVC wire insulation may be expected. Ionization smoke detectors are particularly suitable where flaming fires involving any other materials would be the case. The particle counter detector responds to all particle sizes equally, so they may be used without regard to the type of fire expected. These systems, however, are fairly expensive and complex to install and maintain. The design and layout of the sampling tubes is critical and must be done by someone familiar with the equipment.

Flame detectors are extremely fast responding but will alarm to any source of radiation in their sensitivity range, so false alarm rates are high if they are improperly applied. Flame detectors are usually used in hyperbaric chambers and flammable material storage areas where no flames of any sort are allowable.

Flame detectors are "line of sight" devices, so care must be taken to ensure that they can "see" the entire protected area and that they will not be accidentally blocked by stacked material or equipment. Their sensitivity is a function of flame size and distance from the detector, and some detectors can be adjusted to ignore a small flame at floor level. Their cost is relatively high but they are well suited for areas where explosive or flammable vapors or dusts are encountered as they are usually available in "explosion proof" housings.

Table 1 contains a summary of the information contained in this section.

4. System Features

The fire alarm systems to which the detectors are connected provide many features of operation in response to code requirements. The best way to understand the concepts involved is to discuss systems design and operation in terms of these features.

4.1 Power Supply

All systems are required to have at least two independent sources of power. The primary source is normally from the public utility and the secondary supply from rechargeable batteries (within or near the panel) or from an engine driven generator where such is present for other purposes (such as in a hospital). Switching from the primary to the secondary source is automatic and such switching produces a trouble signal to notify maintenance personnel that the primary source has failed.

4.2 Supervision

This refers to the monitoring of the integrity of the signal transmission paths which interconnect the system components (e.g., the field wiring). The occurrence of any single fault, such as a broken wire or ground fault, which prevents the normal operation of the system must produce a trouble signal. Where a high level of reliability is needed, circuit arrangements which will continue to operate in spite of a single fault are available.

4.3 Signal Initiation

Signal initiation relates to the initiation of a fire alarm signal. This can occur by the activation of an automatic detector, a manual fire alarm station, or a water flow device within an automatic sprinkler system.

4.4 Indication/Notification

Signal indication refers to the process of notification of the existence of a fire. The important considerations here are who is to be notified and how they are to be notified. For building occupants, a combination of audible and visible devices are used. In large buildings where anything other than complete, immediate evacuation of all occupants is contemplated, voice message systems are used where specific instructions can be given to the occupants from a central location in the building.

4.5 Signal Transmission

This relates to the automatic transmission of alarms to the fire department. This may be done directly or through a privately operated alarm monitoring facility. In the U.S., unlike most other countries, most fire alarm systems are not connected to call the fire department automatically. The reasons for this are unclear, but are probably based on tradition.

Transmission is largely by wire pairs leased from telephone companies, although, in recent years, radio transmission techniques have been developed.

4.6 Hard Wire/Multiplex

Traditionally, signal transmission on wires within a building has been on individual dedicated circuits containing one or more initiating or indicating devices within a room or section of the building. Modern electronics has now allowed a significant reduction in the required wiring by multiplexing (mixing) signals on a single wire pair. Groups of devices on this pair are identified with an address and thereby maintain their distinction from other groups of devices.

4.7 Addressable Systems

The next step from multiplex is where each device has its own address. By this process all devices can be on one pair and can be individually controlled. Inquiries on the status of every device are made automatically by the system, performing the function of supervision as well as operation.

4.8 Analog Systems

The newest concept is the detector which transmits data to the panel on its signal level. This allows the signals to be analyzed and compared and a decision algorithm to be applied to decide whether an alarm should be produced or what level of response is needed. Such a system can drastically reduce false alarms.

5. Testing and Maintenance

A detailed guide on testing of complex fire alarm systems has recently been produced. The important concepts contained here (beyond the details of testing procedures and schedules) are as follows.

After initial installation or any major modification, an acceptance test is performed where every device in the system is tested for proper operation. If successful, the system is certified by the installer/contractor that it is fully operational.

A reduced scope recertification test is then required every 5 years, with sample testing of individual devices specified at shorter intervals.

Table 1. Summary of Detector Application Considerations

Detector Type	Response Speed	False Alarm Rate	Cost	Application
Heat	Slow	Low	Low	Confined Spaces
Smoke	Fast	Medium	Medium	Open or Confined Spaces
Flame	Very Fast	High	High	Flammable Material Storage
Particle	Fast	Medium	High	Open Spaces - High Value

FIRE STATISTICS AND THEIR USE IN FIRE PROTECTION

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Introduction

Each time there is a fire incident, whether it is in a residence or a factory, a variety of people and agencies will need to have questions answered about when, where and how the fire started, what the losses were and what factors contributed to the loss. The extent and detail of the data needed will vary widely depending of who the data user will be. Data may be needed to establish the value of insurance claims, to provide budget input and performance measures for the fire department or to allow the code officials and the design communities to evaluate the effectiveness of fire protection and fire prevention measures.

The purpose of this paper is review the basic elements of fire incident reporting and to discuss the potential uses of fire statistics as related to specific user groups. In addition, various techniques will be presented to provide guidance for the analysis of fire statistics.

Fire Reporting Data Elements

The information collected in any data system is largely user dependent and the larger the number of different user needs, the larger and more complex the system will be. A partial list of users includes fire departments, code writers, regulatory authorities, standards committees, insurance companies, researchers, industry and the design community (1). While the specific needs of these groups are often highly specialized, many data requirements are the same. Thus it is important for data to be collected in a consistent manner regardless of the source if members of the fire protection community at large are to interact with each other.

Developed by the National Fire Protection Association (NFPA), NFPA 901, Uniform Coding for Fire Protection, provides a core of fire incident data elements that can be used to provide basic information for a wide range of users (2). These elements have specific definitions and describe the essential facts of a given fire incident. This guide for coding of fire incident data serves as the basis for the National Fire Incident Reporting System in the United States (NFIRS) (3) and is also used at the state and local levels. Australia is presently in the process of adapting NFIRS as the Australian Fire Incident Reporting System (AFIRS)(4). Although NFPA 901 provides data elements for both property damage and casualty (death or injury) reporting, the following overview will focus on property damage.

Since many factors relating to a fire are dependent upon the use of the property involved, an extensive coding system is provided for this data element. Broad categories, such as "public assembly", "health care" and "industrial" have been chosen to be consistent with the same terms as used in building codes and fire protection design standards. Characteristics of the building, such as construction type and method, age of the building, size and value, are identified. Here, for example, it would be noted whether or not the building was of fire resistive construction. Exit features, interior finish and fire protection features such as protection of vertical openings and the extent of sprinkler or detection system protection provided can also be described. Data elements for the activities of the fire department are also provided.

The area of origin and factors resulting in the ignition are also detailed. Equipment involved in the ignition and the form of the heat of ignition are included as well as the form of the material ignited. Forms of materials include building components, furniture, apparel, etc. The type of material ignited is often a critical factor in the outcome of a fire and is classified in NFPA 901 as wood ("naturally occurring fuels"), gas, flammable liquids, chemicals, plastics, etc.

An ignition factor classification is provided to describe the circumstances that permitted the ignition source to act upon the first material ignited. This element can be essential to development of preventive measures. Ignition factors include incendiary, misuse of heat or materials as well as mechanical, design and operational deficiencies. In addition to the ignition factors, data elements to describe factors contributing to flame and smoke travel are enumerated. Vertical and horizontal openings, interior finish materials and building contents are among the choices.

Performance of the fire department or the built-in fire protection systems is important information for the assessment of fire safety measures. Data elements here address such problems as delay of alarm or agent application in terms of detection and automatic or manual suppression.

Specific attention is also paid to measurement of fire losses and manpower use. Here, data elements are provided to distinguish between the damage directly from fire and that from the efforts to suppress the fire. The number of people made homeless or the number of businesses made unusable can also be reported along with the estimated total property damage.

NFPA 901 also provides guidance for the collection of data relative to the location of the incident, date and time of the alarm and time that the fire department arrived at the scene.

Fire Reporting Systems

As can be readily seen from the brief discussion above, it is unlikely that any one user would either have need of or the resources to collect all the data elements in NFPA 901. What is necessary is for users to develop a selection of elements that suit their specific needs using NFPA 901 as a guide. In some cases, users may have to develop their own "custom" elements perhaps as part of a special study or project.

Simply having a collection of data elements that meet a specific need is not necessarily a "reporting system." The system must include the data gathering step (report forms and manuals), data processing (manual vs computer based) and data analysis.

It should be noted that the results of any fire data analysis are only as good as the quality of the input. Training and quality control in the filling out of reports and entering data are essential. Error traps can be built into computer programs to reject clearly ambiguous reports such as one that indicates a $300,000 loss in a fire that was "out on arrival."

Data Analysis

The simplest form of data analysis would be the generation of summary statistics. These data are often produced for annual reporting purposes and deal with broad categories of fire information. The NFPA reports summary data annually for fire losses in the United States. For, the year 1984, the estimated number of fires reported was 2,343,000, the civilian deaths were 5,240, the civilian injuries were estimated to be 28,125 and the property losses were projected to be 6.7 billion dollars (5). In this report, the summary data were placed in perspective by including the percent change from the previous year, +0.7 percent, -11.5 percent, -10.1 percent and +1.7 percent respectively.

Summary data are also provided for losses as a function of broad property use types such as casualties in residential and non-residential. For a more detailed picture of the residential casualties, this category is broken down into "one- and two-family, apartments, hotels and motels and "other." Data for the NFPA summaries comes from a survey in which a stratified sample of fire departments is sent a questionaire regarding their past year`s fire experience.

Summary data for the United States is also collected using the NFIRS system described above (3). In this instance, the data comes directly from fire incident reports that are collected and summarized at the state level. Data from the participating states is aggregated and analyzed at the national level by the Federal Emergency Management Agency.

Other ways to display summary data include losses per population unit (per 10,000, per 100,000, per million, etc.),losses per monetary unit invested in fire protection (fire department costs, cost associated with code requirements, etc.) and ranking fire cause data by frequency of occurrence. Trends can be shown by plotting summary data over a number of years.

While summary data are useful for providing a general picture of fire experience over time, a more insightful analysis technique is fire scenario analysis. A fire scenario is the description of a sequence of events that caused an ignition and the results of that ignition. Once this sequence has been identified, action can be taken to interrupt the sequence in order to prevent the ignition or modify the outcome of the fire.

A scenario should contain at least the following elements to describe an incident (6).

ELEMENT	EXAMPLE
TYPE OF LOSS	DEATH/INJURY
OCCUPANCY (propertry use)	RESIDENTIAL
TIME	NIGHT
OCCUPANT CONDITION	ASLEEP
IGNITION SOURCE	SMOKING MATERIALS
ITEM FIRST IGNITED	FURNITURE
DIRECT CAUSE OF LOSS	SMOKE AND TOXIC GAS

Other scenario elements that could be included are type of construction, location of the incident, presence or absence of a smoke detector, ignition factors, etc. In industrial applications, ignition source may be broken down into equipment involved and form of heat of ignition.

Based on the information available in the user's data base and the level of analysis, the number of elements in a scenario may vary. Once the scenario elements have been selected, the data base is sorted and the results ranked by frequency of occurrence.

The following is an example of the results of a scenario analysis of one- and two-fatality fires in the United States from 1971 to 1978 (7).

HEAT OF IGNITION	MATERIAL IGNITED	AREA OF ORIGIN	% OF DEATHS
Cigarette	Furniture	Living Area	17.3
Cigarette	Bedding	Sleeping Area	14.7
Vehicle Crash (highway)	Fuel	Fuel Tank	3.9
Match, Lighter Candle	Bedding	Sleeping Area	2.3
Heating, Cooking Equipment	Structural Component	Living Area	1.7
Cooking Equipment	Clothing on Person	Kitchen	1.5

Although the above represents only a portion of the results, it can easily be seen that if the firesafety objective is to reduce one- and two-fatality fires, the biggest impact could be made by attacking those scenarios involving cigarettes in contact with furniture or bedding. Four possible strategies might now be proposed... firesafe cigarettes; smoulder resistant furniture, mattresses and bedding; early alerting of occupants through expanded use of smoke detectors, and early suppression of the fire by automatic sprinklers. Clearly, additional study of the costs and relative benefits of the alternatives would be necessary before a final strategy could be selected. Discussion of the various techniques of decision analysis is beyond the scope of this paper. A thorough decision analysis of the cigarette-upholstered furniture scenario can be found in reference 8.

Data Users

As previously mentioned, there are a wide variety of potential users of fire statistics. In the discussion to follow, some of the user groups will be identified along with examples of how the data might be used to meet objectives. It should be noted, however, that in many instances, the needs of several user groups will be found within a single organization. This is often the case, for example, when the fire department has responsibility for development and administration of the fire portions of a building code. A second example might be a large manufacturing company that has its own fire brigade and corporate loss prevention program.

The fire department is the principal generator of fire statistics and is often in the position to make the most immediate use of the data. Sudden increases in the frequency of a particular type of fire, for example, may be dealt with by a targetted inspection or fire prevention education program. Monitoring of the frequency of the targetted fires over a period of time can be a measure of the effectiveness of a special prevention program. High work loads in a particular fire district can be identified and used as the basis for budget requests or reallocation of resources. Concentration of suspicious fires in a particular area of a city or plant may justify surveillance or studies of the ownership, fire and insurance history of the premises in question. These activities often lead to the identification of possible arsonists.

People and organizations that develop laws, regulations and test methods also make use of fire statistics. High death rates or property losses from a particular fire scenario can focus attention and lead to solutions. The following example from the United States experience how this process is carried out.

In 1953, in response to serious injuries from ignition of brushed rayon sweaters ("torch sweaters"), The Flammable Fabrics Act became law. The test method required by the law for apparel fabrics screened out those that were so highly flammable as to be dangerous (i.e. like the torch sweaters) (9). In 1970, a National Bureau of Standards study of detailed reports of burn injuries from apparel fires revealed that young children (0 to 5 years) wearing sleepware were injured more frequently than expected from their percentage of the total population, 1.6 times for girls and 3.9 times for boys (10). A new test for children's sleepware fabric was proposed that evaluated the candidate fabric under ignition and burning conditions that more closely resembled actual scenarios with the sample vertical rather than 45 degrees. The proposed standard became law in 1971 for garments up to size 6X (11) and was later extended to include sizes 7 through 14 (12).

In this example, statistics were used to identify a problem area and the research and testing community used detailed ignition scenario information to develop a proposed solution directed specifically to the problem of reducing the number of children injured in sleepware fires. Legislators and regulators then reviewed the statistics and the proposal along with public and industry responses and the laws were enacted.

Code authorities and committees responsible for development of firesafety design practices have many uses for fire statistics. If, for example, a code authority is considering new requirements for installation of smoke detectors, a study of effectiveness of similar requirements implemented in another jurisdiction or occupancy would be helpful. Such a study might compare the termination stage of the fire or the condition on arrival of the fire department with the presence or absence of detectors.

A study of the extent of flame damage compared to number of sprinkler heads opening for different materials ignited may help improve design standards by identifying the need for greater water application rate if certain materials are expected to be involved. This same study would have value to an insurance company in the process of establishing rates such that enough premium is generated to cover losses. Many other examples can be cited where the use of fire statistics is an essential part of firesafety decision making and risk management.

Summary

If lessons are to be learned, past fire experience, data about fires must be collected and studied by a variety of interested parties. Selection of the data elements to be used in any fire data system or special study must take into consideration the specific needs and objectives of the user. While NFPA 901 provides an extensive set of fire reporting data elements, it may not be practical or necessary to collect them all. In fact, some of the data elements needed for special studies may not be included. In order to make any data system useful to as many users as possible it is important to establish a core of common data elements and definitions and to pay particular attention to accuracy and quality control of the data.

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FAILURE ANALYSIS AND ANALYTICAL FIRE INVESTIGATION

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INTRODUCTION

Failure in a firesafety context can be defined as a fire event that results in personal injury, death, property or monetary losses or in conditions that prevent buildings or mechanisms from functioning as designed (1). The objective of fire failure analysis is to use the on-site and background data, the results of testing and the reconstruction to identify the primary and contributing causes of the failures and their sources.

The sources of failures include basic design, material or equipment selection, material or equipment defects (manufacturing), construction or assembly, testing, post-construction modifications, service conditions (wear and tear) and unanticipated conditions (abuse).

The objective of a failure investigation is to determine the primary cause of the fire, assess the importance of contributing causes and to take corrective action through changes in codes and design practices to prevent similar failures in the future. Targeted inspection or public education programs may also result from understanding the cause and origin. A complete failure analysis can reveal the fuel and building and fire suppression factors that resulted in the ultimate extent of flame and smoke movement. The results of a failure analysis also provide input to insurance loss adjustment and underwriting, and to civil and criminal litigation.

THE ROLE OF TIME IN FAILURE ANALYSIS

A complete reconstruction and failure analysis involves developing a time history for the incident. Time provides the framework for the analysis and can be viewed in two scales. The two scales are the macro or pre fire scale, where time is in increments of days, weeks and years; and the micro or trans fire scale which is meausured in seconds, minutes and sometimes hours.

Through the reconstruction process, events are placed in time perspective. Events to be considered from this perspective include those in pre fire history, as well the trans fire events (those occurring from the point of established burning to extinguishment). Failure analysis deals with the design, construction and performance aspects of the incident in the context of the applicable standards of design and state-of-the-art knowledge and also as a function of time.

Time lines or event sequences are the best way to organize reconstruction and failure analysis information (2, 3). In constructing a time line, it is important to establish reference events. A reference event can be described as an event that is well documented in time and space and serves as a point of reference. The issuance date of a building permit or the time of arrival of the fire department apparatus are good examples. Using time of arrival as a reference event, for example, other events can be roughly placed in time as happening either before or after arrival of the apparatus. Explosions and the collapse of walls or roofs are further examples of typical reference events.

A single line can be adequate for incidents having few events. For more complex situations, separate time lines (on the same scale) can depict the history of the building, evolution of the "model codes," installation and maintenance history of a suppression system, human activity or any other time-related aspect of the incident.

The sources of pre fire time line information include building permits, plans and specifications, inspection reports, fire and building codes and the fire research and engineering literature.

The fire department incident report, recordings of fire department radio transmissions during the incident, and personal interviews with fire fighters and other witnesses are among the many sources of information for use in the development of trans fire time lines.

THE RECONSTRUCTION AND FAILURE ANALYSIS PROCESS

The basic steps of reconstruction and failure analysis are examination of the scene, collection of background data, testing, reconstruction and failure analysis.

Fire Scene Examination

The examination of the fire scene is critical to the entire reconstruction and failure process. During fire scene examination, the physical and photographic evidence is gathered. The extent and kind of damage is documented during fire scene examination.

As part of the fire scene examination, the investigator will take as many photographs as possible. Each photograph should be documented on a diagram with a description of the direction of view and what is being shown. In addition, maps and diagrams should be prepared which note the dimensions and interior layout of the building, the location and degree of damage, location and types of fuel materials, and the locations of victims. The location of fire protection features such as fire walls, detectors and suppression systems should also be noted.

Many buildings will be modified considerably over their lifetimes. Consequently, reviewing the original plans of the building would provide a false impression of the building at the time of the fire. For this reason, recording the architectural, construction and fire protection features at the time of the fire is very important.

When fire suppression systems are present, the investigator should note the position of valves, locations of discharge nozzles and location and type of detectors used to operate the system. With special agent systems (such as halon, CO_2 or dry chemical), agent storage tanks should be checked to determine whether or not the system discharged as designed.

Careful study of the damage patterns, combined with interviews and a knowledge of the ignition sources and fuel materials present immediately prior to the fire should be used to determine the area of origin and if possible the source and form of heat of ignition and the type and form of the materials first ignited (4). Burn patterns such as "V's", low burns and multiple "points of origin" can often be misleading. Consequently,they should only be used in establishing cause and origin when unambiguous or supported by other physical evidence. It is often very helpful, in visualizing conditions in the area of origin, to physically reconstruct the scene by replacing items in their original locations.

Interviews may be conducted at many different times in the reconstruction and failure analysis process. However, those taken at or close to the time of the incident can be especially useful, particularly in describing the course of the fire. Whenever possible, try to relate events described in interviews to reference events for the time lines.

Background Data

Although some of the background data (such as activities immediately prior to the fire) can be gathered at the scene very soon after the fire, the majority of needed information will be gathered later.

The investigator will obtain plans, permits and the codes in effect at the time of approval, along with the specifications and drawings for the fire protection features. These same materials should also be obtained: (1) if the building experienced any major modifications; (2) if the building's fire protection features were altered; or (3) if there has been a change of occupancy. Since any of these changes may have influenced the course of the fire, a review of these materials should be undertaken during the reconstruction process. Codes applicable at the time of any changes to the building as well at the time of the fire should also be studied.

Additional background information that may be useful for the reconstruction could include instruction or training manuals, maintenance records, data on construction and interior finish materials, previous fire history of the building or equipment involved, the amount of any previous fire damage, and the physical and burning characteristics and the location of the contents. The gathering of background information also involves obtaining detailed statements from the building occupants as a way of determining the circumstances that lead to ignition and established burning.

Testing

Reconstruction and failure analysis may involve three types of testing: (1) standard tests of flammability properties; (2) standard analysis of unknown materials; and (3) special tests designed to establish burning hehavior under conditions related to a specific fire scenario.

The many standard tests of flammability properties include flame spread of materials (5,6); fabric flammability (7,8); flash point (9,10); and rate of heat release (11, 12). Analytical laboratories conduct debris analysis using techniques such as gas chromatography, mass spectroscopy and others to identify unknown materials, particularly possible accellerants. Metallurgical or x-ray analysis are also useful techniques.

Special tests that attempt to replicate a given fire are sometimes called "demonstrations," and can often be extremely revealing in understanding the course of a particular fire. However, the results of demonstrations can be misleading or subject to question about whether or not the demonstration represents what actually happened. Factors such as ventilation, arrangement of the fuel or even the point of ignition can have a significant effect on the outcome of the test. In other words, the specific conditions at the time of the fire must be well understood and reasonably reproduced in the demonstration. Special tests or demonstrations should be conducted under laboratory conditions.

Reconstruction

The fire reconstruction is an organized, step-by-step portrayal of the most likely course of the fire in question from the ignition sequence through established burning to the limits of flame and smoke movement at the time of extinguishment. It is based on the facts developed through on-the-scene investigation, background studies and testing. The reconstruction explains the fire growth within the compartment or area of origin, along with the effects of barriers and automatic suppression systems on spread and growth and of the effects of manual extinguishment. The reconstruction should also include an evaluation of how the life safety features of the building performed, relative to injury of loss of life.

In sorting through the facts to develop the reconstruction, the investigator may find it useful to apply the system safety techniques of Failure Modes and Effects Analysis (FEMA) and Fault Tree Analysis (13). These methods help identify alternative sequences of events that could lead to the observed fire situation such as development of room flashover or fire breaching a fire wall. The investigator may then evaluate the alternatives against the evidence to determine the most likely scenario. These techniques are particularly valuable where complex or interrelated machinery, buildings or human activities are involved.

Analysis of the ignition sequence is concerned with three specific items: the size, nature and source of the ignition energy; the physical and chemical properties of the fires materials ignited; and the circumstances (human or mechanical) that brought the energy in contact with the fuel. In selecting the most likely ignition source, the investigator must compare the energy available from a candidate source with the ignition energy requirements of the fuel in the given form. For example, given the same material and heat source, ignition is more likely for materials in finely divided form than for solid materials. Energy available at the source (temperature, thermal radiation, etc.), distance from the fuel to the energy source and time of exposure to the source of energy are also factors that must be considered.

The circumstances which result in ignition generally involve human or equipment failure. Human failures include factors such as careless welding, poor housekeeping and improper selection or misuse of materials. Valve rupture and combustion control failure could be considered equipment failures. Ultimately, most equipment failures can be traced to design, manufacturing, installation, misuse or maintenance problems.

If it is assumed that established burning is achieved after ignition, the investigator must determine why the fire continued to full room involvement (flashover) or, in the absence of compartmentation (such as in a warehouse or industrial building), reached the extent that it did. The investigator will evaluate a number of factors--including the rates of heat release of the fuels, continuity of the fuels (proximity of fuel packages to one another), location of fuels relative to walls, compartment ceiling height, ventilation and interior finish--in making these determinations.

Heat release rate is one of the more important factors. In many instances, a fire that was reported to have grown or spread "unusually fast" is characterized as suspicious or incendiary when, in fact, the growth rate may have been due to a combination of the burning properties of the materials and nature of the compartment in which the fire burned. A number of studies have been carried out to characterize the burning rates of materials and furnishings. Data can be found in National Bureau of Standards reports (14 - 17). The roles of heat release rate, fire location and compartment geometry have been reported by Lawson and Quintiere (18). Their work includes methods to estimate ceiling temperatures, smoke levels, time to flashover and flame height. Guidance on estimating the likelihood that a given fire size and room ventilation combination can develop flashover is provided by Babrauskias(19). A number of computer models are also available that may be used to "test" various possible fire scenarios.

Caution must be used, however, when applying fire models and calculations. Some models may not be accurate if room doors are assumed to be closed. Others may yield misleading results if the wrong heat release rate is used. It is important to study the formulas and the input data on which each model is based. A sensitivity study should also be conducted to determine the most critical variables. This is particularly important when assumptions must be made regarding the inputs.

The reconstruction also involves evaluating the performance of automatic suppression systems in controlling the growth and spread of the fire. Among the factors to be reviewed are the appropriateness of the agent being used, and the response time of the system as related to the detection devices used relative to ceiling height and fire growth rate. In addition, the investigator will review the location of the agent discharge nozzles relative to the source of the fire, and agent availability (rate of discharge, pressure and adequacy of supply). The conformance of the system design and installation with the recommended practices found in NFPA standards and industry design and installation manuals should also be reviewed. For example, a sprinkler system may have failed to control a fire due to a very high ceiling (that delayed the response time), combined with low water pressure that could not produce the needed water flow rate.

Barrier performance evaluation focuses on the nature of the barrier (rated or not rated), the construction, the thermal stresses to which it was exposed and the manner in which the barrier failed. Barriers can fail either by passage of flame or hot gases through a small opening, a hot spot failure, or by movement of flame and hot gases through open doors or barrier collapse resulting in a massive failure. Failure of opening protection, poor construction practices, modifications to the barrier after construction (poke-throughs, etc.) and fire stresses that exceed those assumed in the design are examples of the causes of massive failures.

Manual suppression activities, including those by a municipal fire department or a plant fire brigade, can have significant effect on the outcome of a fire. In the absence of fire suppression systems, the response time of the fire department will determine the size of the fire at agent application. For ease of analysis, the response time can be broken down into the following segments: detection time, alarm transmission time, dispatch time, travel time and time from arrival to agent application. Problems resulting in delays in any of the above time segments will extend the limit of flame and smoke travel.

Examples of factors that could cause delays are the absence of detectors, unoccupied building or an improperly designed detection system. Equipment failure or fire apparatus out of service can delay response time; weather, terrain, traffic or condition of apparatus can extend the travel time. Malfunctioning hydrants, blocked access or shortage of personnel are examples of factors that could delay application of water.

The reconstruction may often consider the performance of the building life safety system. This includes the detection and alarm system and the building egress system. In addition to the factors effecting detector response discussed above, the audibility of alarms plays a role in life safety. Guidance on this topic can be found in work by Nober (20). Building egress factors include the capabilities of the occupants and the number, capacity and protection of the means of egress routes.

Failure Analysis

A failure analysis is made by comparing the causes of failures with the codes, standards, design practice and the state-of-the-art technology. In the analysis, it is important to identify noncompliance with the standard practices, but it is even more important to note where compliance with the standards failed to provide the expected or needed fire safety. In either event, the failure analysis should provide recommendations for how the failures could have been prevented in the fire in question or how the knowledge gained can be applied to preventing similar failures in the future.

CONCLUSION

In many fire incidents, the size of the loss does not appear to warrant an in-depth analysis such as that outlined above and only the big losses are studied in detail. Often, the need for a complete analysis may not be recognized until after the scene is destroyed. Thus it is important to assure that at least the fire scene and witness statements are adequately documented for possible future use in reconstruction and failure analysis.

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FIRE ORGANIZATION IN THE UNITED STATES

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INTRODUCTION

There is no single organization in the United States with overall responsibility for fire safety. Fire protection standards, services, research and education are handled by a variety of private sector organizations, federal, state, and local governments and universities. The primary body involved in the development, publication and dissemination of fire safety standards in the USA is the National Fire Protection Association. The major organization which develops standard test methods to measure the fire properties of materials is the American Society for Testing and Materials. Public fire protection at the local level is provided by over 28,000 independent fire departments. The Society of Fire Protection Engineers is the professional technical organization of qualified fire protection engineers. The Center for Fire Research is the focal point for fundamental and applied fire research in the USA, and the University of Maryland is the only academic institution currently offering an accredited 4 year undergraduate degree program in fire protection. This paper provides further details of the activities of these and other private and government organizations associated with fire protection.

STANDARDS

Federal Regulations, Specifications, and Standards

Several Government agencies (e.g. Housing and Urban Development, Transportation, Occupational Health and Safety) have regulatory authority for specific activities and products, and reference federal, national concensus or industry standards and specifications in their codes and standards. Most of the Federal specifications and standards prepared previously by Government agencies for regulation, procurement and quality control purposes, have been replaced by national concensus standards developed by private standards writing organizations such as the National Fire Protection Association, the American Society for Testing and Materials and Underwriters Laboratories.

The National Fire Protection Association (NFPA)

NFPA is a non-government, voluntary membership, non-profit organization with its headquarters in Quincy, Massachusetts, (near Boston). It has a membership of approximately 32,500 individuals, 140 national trade and professional organizations, and a staff of more than 200.

Activities of NFPA fall into two main areas, technical and educational. The technical activity involves development, publication and dissemination of standards which form the basis for voluntary fire safety practice and for mandatory building and fire code requirements. Each standard is published as an individual booklet and all appear in the annual, multi-volume set of National Fire Codes. The most widely used individual booklets are the National Electrical Code, the Life Safety Code and the Flammable and Combustible Liquids Code. The educational activity involves promoting public adherence to the standards and making good fire safety habits a way of life. In addition to its standards and codes, NFPA publishes a number of books including the Fire Protection Handbook, now in its 15th edition, a quarterly technical journal and a monthly magazine. NFPA also assembles and analyzes national fire loss statistics based on data provided by state fire marshals and performs on-site investigations of significant fires. At its annual meeting in May each year NFPA hosts a major fire safety exhibition of fire protection equipment and services.

American Society for Testing and Materials (ASTM)

ASTM is a non-government, non-profit, scientific and technical organization that develops standards on the characteristics and performance of materials, products, systems and services. Of the 137 main technical committees only one is primarily concerned with fire. It is Committee E5 on Fire Standards. It monitors and regularly updates approximately 20 standards, of which the most widely known are E 84 Test for Surface Burning Characteristics of Building Materials, E 119 Fire Tests of Building Construction Materials, and E 152 Fire Test of Door Assemblies and E 108 Fire Tests of Roof Coverings. Other standards involve measurements related to combustibility, flame spread and smoke generation, and recently Committee E 5 has added combustion toxicity, risk assessment and fire modeling to its areas of activity.

SERVICES

Testing Services

Fire testing of materials and products is generally not a government function in the United States, it is performed by private laboratories such as Underwriters Laboratories Inc., United States Testing Co., Inc., Southwest Research Institute, Factory Mutual Research Corp., and university laboratories. It has become common practice for safety authorities in state and local jurisdictions to recognize the results from independent testing laboratories rather than set up their own facilities.

Fire Services

In the U.S. there are over 28,000 fire departments providing public fire protection at the local level. Depending on size and location of the city or area covered, the fire departments may consist of career (paid) firefighters, volunteer firefighters, or a combination. Fire departments vary widely in size, the largest being New York City which protects more than 7 million people, has 12,000 fire fighters, and operates on a budget of more than 4 million dollars. The two major organizations representing fire service personnel are the International Association of Fire Chiefs and the International Association of Fire Fighters. The chief fire protection administrator at the state level is called the State Fire Marshal, and the State Fire Marshals Association of North America serves as the principal organization of fire marshals, fire prevention officers and fire investigators.

RESEARCH

The Center for Fire Research (CFR)

The Center for Fire Research at the National Bureau of Standards is located in Gaithersburg, Maryland close to Washington, D.C. With a staff of more than 100, CFR's scope extends from exploratory research on combustion to the development of computer programs to solve practical fire protection engineering problems. The program includes flammability and toxicity measurement, fire growth and extinction phenomena, room fire modeling, hazard analysis, fire simulation, fire performance and validation testing. In addition to its own inhouse research the Center also provides grants to nearly thirty universities. Approximately 50% of the work of the Center is performed for other Federal agencies.

Other Federal Fire Research Laboratories

Fire research programs are underway at a number of other Federal laboratories. These include the Forest Service, the Naval Research Laboratory, other defense laboratories, the Federal Aviation Administration and the Consumer Product Safety Commission. These and other Federal agencies sponsor research at government, private and university laboratories. These programs are much narrower in scope, more applied, and mission oriented than that of the Center for Fire Research.

Private Sector Research Laboratories

Factory Mutual Research Corporation (FMRC), located near Boston, is the leading fire research laboratory outside the Federal government. It is supported by a group of insurance companies to provide guidance on protecting properties they have insured to minimize their risk. It has a well equipped large scale test facility which has been used to pioneer the development of fire suppression systems for warehouse storage protection.

Southwest Research Inc. (SwRI), an independent research organization located in San Antonio, Texas has a department of fire technology. The primary focus of the work in fire at SwRI is on the evaluation of the fire performance of construction materials and the investigation of the toxicological effects of smoke and gases produced in fires.

Underwriters Laboratories Inc. performs some fire research, but most of its work is associated with product testing to ensure conformance with fire test standards.

EDUCATION

Society of Fire Protection Engineers (SFPE)

SFPE, although smaller than the professional societies of the major engineering disciplines such as civil, mechanical and electrical, has similar goals and objectives. It has forty local chapters in the United States, Canada and Europe. Technical meetings and symposia are held at local and chapter levels, and the society publishes a limited number of technical reports and symposia proceedings. A most significant event in SFPE's history occurred in 1981 when it started to administer the fire protection engineering-Professional Engineer (PE) registration examination.

The United States Fire Administration (USFA)

The USFA, which is part of the Federal Emergency Management Agency (FEMA), is located at Emmitsburg, MD about 70 miles north of Washington, DC. It has a staff of less than 20 professionals but manages a 9 million dollar program of contracts and grants to others. The program includes promotion of residential sprinklers, public education and awareness, firefighter health and safety studies, data collection and analysis, fire service management studies and arson prevention studies.

The National Fire Academy

The National Fire Academy, is an organizational part of FEMA's activities in training and education. Also located at Emmitsburg, it is a residential training center providing advanced training to fire service personnel. The programs offered usually last two or three weeks and range from executive fire officer development and fire service management to line officer training.

Universities

The University of Maryland, a large State university with a total student population of nearly forty thousand, is the only college in the United States currently offering a four year program leading to a bachelors degree in fire protection engineering. About 30 students graduate each year, most finding jobs with private industry fire protection engineering consultants, government agencies or insurance companies.

Worcester Polytechnic Institute (WPI), a private college located near Boston, is the only college in the U.S. that runs a formal master's degree program in fire protection engineering. Students in this program at WPI typically have a prior bachelors degree in an engineering discipline. In addition many colleges offer 2 year or 4 year degrees in fire science, fire technology or fire administration.

CONCLUDING REMARKS

As can be seen from the above descriptions, fire protection organizations in the United States vary widely in size, anatomy and funding. There is no overall coordination of these activities, and yet each performs its functions well without major attempts to eclipse those of the others. The fire record of the United States is not as good as those of many other developed nations for various reasons, so each of the above organizations needs to make maximum use of its resources to do its share in reducing the toll of life and property loss in unwanted fires.

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Industrial Fire Suppression

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Introduction

Fire protection of industrial facilities involves four different but mutually compatible approaches, namely, the use of non-combustible materials for construction, compartmentation, automatic suppression systems, and smoke control and removal systems. The first two are passive the others are activated after detection of the fire. Of the four, only automatic suppression systems are designed to put out the fire, the others merely control the extent of the fire until the fire brigade arrives. This paper focuses on automatic sprinkler systems, their design, performance, application and testing. Brief reference is made to other suppression systems using foam and halon extinguishing agents.

Design

The primary features of a sprinkler system are the water supply, which may be fed by gravity, stored pressure, or a pump, a fire main and a series of sprinkler networks. Each sprinkler network consists of a supply pipe, a stop valve, an alarm valve, and a series of distribution pipes at ceiling level on which the sprinkler heads are mounted. General design of the piping system can be done using sets of tables ("pipe schedules") or by hydraulic calculation. Computer programs are available to perform these somewhat tedious calculations. Sprinkler heads themselves have three essential parts, namely a nozzle, a releasing device, and a deflector. The most common form of releasing device in the United States is a soldered link element which opens the nozzle when the solder reaches its melting point. Other types include a glass bulb containing a liquid that expands when heated and bursts the bulb, and a low - fusing chemical that liquifies at the rated temperature and allows the strut holding the valve closed to collapse.

Standard sprinklers can be upright or pendent. Upright sprinklers, which are mounted above the supply pipe are marked "Upright-SSU", and pendent sprinklers, which are mounted below the pipe, are marked "Pendent-SSP". The main disadvantage of pendent sprinklers is that the piping cannot be drained quickly when freezing is anticipated. Other types of heads include flush type which are mounted in the pendent position but flush with the ceiling to improve appearance, and sidewall type which are equipped with a special deflector so that most of the water is discharged away from the wall against which the sprinkler is mounted. Sidewall sprinklers have become popular because they are generally easier to install in retrofit situations.

For industrial applications both closed pipe and deluge (open pipe) systems are used. The closed systems either contain water under pressure (wet pipe system) or in unheated buildings in climates where freezing is possible, air under pressure (dry pipe system). In both wet pipe and dry pipe systems water flows only from the sprinkler heads that are activated by the fire. The deluge system has open sprinklers and is used when it is desirable to wet down the whole of the protected area. The water supply is held back by a deluge valve which is actuated by a system of heat responsive sensing devices throughout the protected area. A variation of the closed system is the pre-reactive system where the water is held back by an automatic control valve which, like the deluge system, is actuated by a system of heat responsive devices. This precharges the system but the water discharges only when the sprinkler heads themselves open.

Performance

The performance of a sprinkler systems depends on many factors including:

1. The actual operating temperature of the device
2. The thermal capacity of the link material
3. The heat transfer from the air to the sprinkler
4. The rate of growth of the fire
5. The height of the ceiling
6. The shape of the ceiling
7. The thermal qualities of the ceiling
8. The distance between the sprinkler and the ceiling
9. The horizontal distance between the sprinkler and the fire
10. Factors that will effect the flow of gases from the fire to the sprinkler

Sprinklers are available with normal operating temperatures ranging from 57°C to 260°C. Soldered link sprinklers generally have less variation from the nominal operating temperature than the glass bulb type.

The thermal capacity of the sensing element controls how quickly the sprinkler will actuate when immersed in hot gas. The higher the thermal capacity the slower the response. The trend in the United States is toward "fast response" sprinklers. The speed of response of a sprinkler can be identified by a "Response Time Index" which ranges from 100-400 $m^{1/2}s^{1/2}$ for standard sprinklers to 25-50 $m^{1/2}s^{1/2}$ for fast response units.

The slower the response of the sprinkler the larger a growing fire can become by the time the sprinkler activates. Hot gases from a fire fill a room from the ceiling down so other than immediately above the fire the greater the distance between the ceiling and the sprinkler the slower the response. Obviously the shape and thermal properties of the ceiling and the ventilation patterns also effect the temperature rise at the sprinkler.

Sprinkler systems have in general been reliable and very effective. The primary reason for system failures has been shut off supply valves.

Application

The general rules governing the installation of sprinklers in the United States of America are laid out in the National Fire Protection Association Standard 13. The primary factors affecting the location and spacing of sprinklers are the type of occupancy, i.e. ordinary hazard or extra hazard, and the type of construction. It would be impossible to cover here all the details contained in NFPA 13 but some special cases may be of interest. In high rise buildings for instance, the performance of sprinkler systems in protecting life has been well documented. Most high rise buildings are used for offices, hotels and residences and as such are classified as ordinary hazard. Extra hazard occupancies include commercial and industrial locations where the fire load is high, i.e. the materials handled, stored or processed are highly flammable such as volatile liquids, wood and cotton, or stored in high rack storage. Some typical locations classified as extra hazard occupancies are aircraft hangers, wood working shops, plastic, foamed rubber, paint and firework manufacturers.

Substantial research is underway to improve protection for high rack storage in warehouses, with in-rack sprinkler systems receiving much attention. NFPA standard 13 covers goods stored up to 4m high and NFPA standard 231 deals with storage up to 7.5m high.

Testing

All sprinkler systems should be tested after installation and an inspection report completed. It is important to flush outside underground piping under pressure before connections are made to sprinkler risers. This is to remove stones or other material which may have entered when the pipes were laid.

A hydrostatic leak test should be performed on the system. The test pressure of 200 lb/in^2 (or 50 lb/in^2 above line pressure if the line pressure is above 150 lb/in^2) should be maintained for 2 hours. The pressure should be maintained with a small pump with the main shut off valve kept shut so that if a leak or burst occurs any water damage will be minimal. Dry pipe systems should have the differential valve latched in the open position. In addition to the hydraulic test, dry-pipe systems should be tested with air at a pressure of 40 lb/in^2 for 24 hours. Any leakage of more than 1 1/2 lb/in^2 in the 24 hours should be corrected.

Deluge and prereaction systems should be tested with a heat source to ensure that all the components (heat responsive devices, alarms, and the deluge valve clapper) are operational.

Finally, a precautionary word concerning maintenance. Whenever sprinklers are shut off for maintenance or repairs a serious protection emergency exists and special procedures should be followed:

1. Work should be scheduled on weekends or idle periods
2. Shut off the least number of sprinklers possible at a time
3. Have tools and materials ready before starting so the shut off time can be kept to a minimum
4. Notify the local fire department
5. Lay out charged hose lines from the nearest fire hydrants and have portable extinguishers available.
6. Tag the shut off valve and establish a follow up procedure to ensure the valve is reopened on completion of the work.
7. Do not leave sprinklers shut off overnight
8. Have the area continuously patrolled

Other Fire Suppression Systems

For protection of high hazard areas such as aircraft hangers and petrochemical areas fixed foam-water spray systems are used. The systems are similar to regular water sprinkler systems except that the sprinkler nozzles are replaced with aspirating nozzles which produce foam when supplied with an aqueous film forming foam solution (AFFF). Obviously the systems include concentrated tanks, proportioners, and pumps. Detailed design requirements are contained in NFPA Standard 16.

Fixed carbon dioxide extinguishing systems are sometimes used for flammable liquid fires, electrical fires and for protection of rooms containing high value contents such as record vaults and computer rooms.

Halogenated systems are also used for protection of high value contents such as computer rooms. Different halons with differing properties are available. The designation, eg. halon 1301, identifies the number of carbon, fluorine, chlorine and bromine atoms respectively in each molecule. Halons are expensive and are generally used to protect small areas only. Recently concern has been expressed over the corrosive properties of the combustion products of halons when used with computer installations. Studies are underway to investigate these concerns.

Summary

Industrial fire suppression systems installed according to published standards have proved to be reliable and effective in controlling fires and reducing losses. However, research into fire suppression and sprinkler system design for special applications is continuing in the United States at both the Factory Mutual Research Corporation and the Center for Fire Research at the National Bureau of Standards, and into other suppression systems by the U.S. military and various manufacturers.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A series of talks were given by the U.S. participants in the Workshop on Fire Protection Technology, within the framework of the cooperation of NBS with Egyptian institutions. The Egyptian institution involved with this workshop is the National Institute for Standards. NBS proposed the Workshop in order to explain the value of fire safety to the intended audience.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

AID, Fire Detection, Fire Organizations, Fire Safety, Fire Statistics, Industrial Fire Supression, Investigations

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